U.S. Superiority In Space—
Considering Propulsion And Power

Lt Col Graham W. "Gray" Rinehart, USAF

At the dawn of the twenty-first century, the US enjoyed a substantial lead in many if not most areas of military space exploitation. For example, navigation signals provided by the US Global Positioning System set the standard and provided near-utility service for anyone who could buy a receiver; in contrast, the Russian GLONASS was an inferior product, the Chinese Beidou system an even less capable attempt, and the European Galileo system an unrealized dream (but one they are still pursuing). Among other examples, the capabilities of the National Reconnaissance Office were widely admired even though their details were hidden in the "black world" of special programs. On the whole, US systems performed better and lasted longer than systems built by any other country.[1]

The only area the US did not lead consistently was space launch. Because US satellite systems outlived expectations, less emphasis was placed on developing new, more reliable launchers.[2] Gradually the US share of the world's launches fell. It may be debated whether the Evolved Expendable Launch Vehicle (EELV) variants—the Atlas-5 and Delta-4—will really end that trend. Part of the worldwide launch decline could be attributed to difficulties with commercial satellite ventures, but it did not help that the US launch industry suffered a terrible series of launch failures between 1988 and 1989,[3] and the February 2003 loss of the Columbia does not bode well for keeping the US launch industry healthy.[4]

If we cannot get to space, eventually our capabilities in space will decline.[5] Falling US launch capability becomes militarily significant in two ways. First, indigenous US capability—in the commercial sector—provides the technical and experience base for US launches. Second, a thriving commercial launch sector could, if needed, form the basis of a Civil Reserve Space Launch Fleet.[6]

In the same way, commercial on-orbit assets could also form the basis of a Civil Reserve Space Fleet for missions ranging from communications to remote sensing.[7] In some respects that fleet already exists: the military leases circuits on commercial satellites and the government buys large batches of commercial imagery, and has done so for many years.[8] As commercial remote sensing capabilities improve, loss of a US government capability through accident or an enemy's design might lead the US to purchase even more commercial imagery for military use.

Still, it is safe to say the US possesses space superiority—but not space supremacy, which would imply we have complete freedom of action and use of our assets while others (or at least our adversaries) have none, or nearly none.[9] And the US used space systems extensively to support military missions over the last twenty years. The preponderance of space assets at our disposal was such a key element to our success in the second Gulf War that before the action started US military leaders expressed pity for the enemy.[10] From space warning's detection of Iraqi short-range missile launches, to navigational signals maintained continuously over the battlefield, to satellite-based communications routing command, control, and situational awareness data for fielded forces, US space operators provided vital enabling functions to every aspect of the Afghanistan campaign of the Terror War and to Gulf War II.

That advantage in space is primarily technological. This may be self-evident with respect to space systems, since we would have no space exploits without the technological systems that make them possible. But since, to a degree, the same could be said for air power or any mode of conflict higher than the bare fist, recognizing the fact of dependence on technology does not by itself give much insight into the current or future state of that technology. Improvements in technologies—especially in propulsion and power—could provide the US with even greater advantage, but to reap the maximum benefit will require commitment and risk from policy makers.

The Technological Edge

We can characterize the US advantage in space in several different ways. For instance, we might compare ourselves country-by-country against our chief competitors, to determine if our advantage persists across the board. We could stratify this further by comparing system-by-system, forming a matrix of comparisons. This type of analysis was done in the March 2001 space systems section of the Militarily Critical Technologies List (MCTL), which included worldwide technology assessments with respect to research and development (see Table 1).[11]

Producing a similar table with respect to capabilities rather than technologies would show no single country currently rivals the US in space expertise. Just because a nation cannot match our capabilities, however, does not mean they are incapable: "More than a dozen countries….can produce imagery, communications, and experimental satellites that, while not always equivalent to top-of-the-line US products, are capable of meeting many military needs."[12] Many nations, which cannot match us head-to-head, still have access to space systems and space-generated information. In addition, some nations may pursue new technologies specifically in order to achieve capabilities different from ours, so they can counter or bypass our strengths.[13] A matrix of capabilities would also show that individual nations might not have access to the entire range of space capabilities, but a coalition could use combined assets to wield useful military space power. For example, a coalition might combine Russian launch vehicles and navigational systems with French remote sensing satellites and Bahraini communications satellites; over time that coalition would be able to exploit the space medium to a certain extent, but the inferiority of some of those systems (e.g., GLONASS) would still leave us with the advantage.

But space capabilities rely on space technologies. At the risk of disappointing pure technologists, whose backgrounds predispose them to their own favored technologies, let us examine selected technologies without which space systems would be either useless or impossible.

Selecting which technologies to study is something of a black art. For instance, the MCTL divides technologies into two sections: Weapon Systems Technologies which are "critical to the development and production of superior weapons," and Developing Critical Technologies which "will produce increasingly superior performance of military systems or maintain a superior capability more affordably."[14] With respect to space systems, the MCTL lists five categories of Weapon System Technologies: Electronics and Computers; Optronics; Power and Thermal

Management; Propulsion; and Sensors.[15] The list of Developing Critical Technologies is more extensive: it includes the first six categories from Table 1, plus Sensors; Survivability; Structures; Integrated Systems; and Space-Based Lasers.[16]

Table 1. Worldwide Technology Assessment for Space Systems (Partial). An example of technological comparisons. (Source: *Militarily Critical Technologies List,* March 2001).

Country	Space Avionics and Autonomy	Electronics and Computers	Launch Vehicles for Space Systems	Space Optics	Power and Thermal Management	Propulsion for Space Systems
Australia		●		●		
Belgium		●				
Canada	●	●		●●	●●	●●
China	●		●●	●●	●	●●●
Finland						
France	●●●	●●●	●●	●●●	●	●●●
Germany	●●	●●●	●●	●●●	●●●	●●●
India	●		●			●●
Israel	●	●		●●		●
Italy	●	●●	●	●	●	●●●
Japan	●●●	●●●	●●	●●●	●●●	●●●
Netherlands		●●				●●●
North Korea						●
Norway			●	●		
Russia	●●	●●	●●	●●	●●●	●●●●
Singapore				●		
South Korea	●●	●	●	●		●●
Spain						
Sweden	●●	●		●	●	●●●●
Switzerland	●●	●		●	●●	
Taiwan	●●	●●		●●	●	●
Ukraine			●	●		●
UK	●●	●●●	●	●●	●●	●●●●
United States	●●●	●●●●	●●	●●●	●●●	●●●●

Legend: Extensive R&D ●●●● Significant R&D ●●● Moderate R&D ●● Limited R&D ●

With so many possible technologies deemed critical in one way or another—an annoying aspect of the two MCTL sections, in that technologies are either critical now or may be critical later—how should we choose a subset to examine? Rather than examine any mission-specific technologies, let us consider the basics necessary for successful space endeavors. The following list of basics is representative:

> **Propulsion.** From the launch pad to maneuvering into the proper orbit, space systems must be able to go where we need them.
>
> **Power.** An obvious necessity, as we have no extension cords long enough to service spacecraft.
>
> **Thermal control.** Space being an environment of extremes, the working components of a system must be kept comfortable.
>
> **Sensors.** A spacecraft must be aware of its environment, and must have the right tools to do its mission.
>
> **Attitude control.** No matter what it was sent into space to do, the system must stay pointed in the right direction.

Electronics. Without electronics, rockets and satellites are just expensive hunks of metal.[17]

Lack of space prevents considering each possible technical element in depth; for the sake of brevity, let us consider how possible developments in the first two enabling technologies above—those that get us where we need to go and give us the power to do what we need to do—may affect our dominance in space in the next 20 years.

The Uncertain Future

Given the inevitability of change and our track records of progress and innovation, we may project what types of space systems may be available 20 years from now. Doing so involves deciding whether we will be optimists or pessimists about our ability—and our willingness—to discover the secrets of these technologies.

None of us can forecast without some measure of hope. We may avoid the worst type of bias—that of skewing our forecast deliberately based on either hope or fear—but true neutrality eludes even the best of us. What is the condition of the proverbial glass? Whether half-full or half-empty, it is only useful to us if we drink from it and fill it again.

Since we cannot predict nor force technological breakthroughs—we can forecast their eventuality, but not their timing—what do we expect of technology? For this analysis we will not consider null cases—in which we assume the status quo continues—primarily because optimism dies hard. We look to the future with hope for at least some progress. So it is prudent to assume US research efforts will continue but not at the levels needed to produce stunning breakthroughs; thus, a realistic assessment is that propulsion and power technology will see some incremental improvements over the next 20 years but not exponential leaps. Finally, since space propulsion and launch vehicle technologies are not receiving equivalent attention (see Table 1), it is prudent to assume they will not progress at the same rate.

This approach may be a shade pessimistic rather than fully realistic, but it can be better to be surprised by good fortune than to count on it.

One: On-Orbit

In this first scenario, we assume launch technology remains fairly static. Without speculating on the makeup of the US launch vehicle fleet, we assume costs per pound do not decrease dramatically; therefore, getting to orbit is as difficult as ever before. At the same time, we assume space propulsion systems have improved. They may be safer versions of nuclear engines or more effective ion engines or laser-pumped systems driven by ground-based lasers; for the purpose of this discussion the actual systems are less important than the outcome: more maneuverability using less propellant over a satellite’s lifetime.

With respect to satellite power systems, we assume improved solar cells and panels produce more on-orbit power. We may neglect for the time being the need for improved power storage or improved thermal control—since power creates heat—and assume the end result is a higher ratio of delivered power to the electrical power subsystem’s mass. At the same time, we may assume satellite electronics will continue to get smaller and more capable because of the semiconductor industry’s pursuit of Moore’s Law.

How will those advancements affect US space advantages?

Taking first the improvements in solar power and electronics technologies, the result should be smaller satellites with the same capabilities as today’s big satellites. Smaller solar panels will produce the same or even greater amounts of electricity, and smaller electronic components will have the same or improved levels of capability and reliability. This is a reasonable continuation of recent experience: “A decade ago, military satellites typically weighed between 5,000 and 20,000 lb. Now those going to LEO increasingly weigh between 500 and 2000 lb.”[18] Miniaturization of electronics has made micro- and nanosatellites possible today; over the next 20 years, the capabilities of those satellites will continue to improve. (Whether microsatellites will be as capable as today’s large, high-power satellites remains to be seen, but certainly in the future better things will come in smaller packages.) These smaller satellites will be able to launch on smaller boosters, which will be an advantage in itself when launch costs are still high.

Alternatively, better power production and electronics will enable us to build the same size satellites as today but make them far more capable. Higher power transmissions will enable communications satellites to cut through interference or weather, and more satellites could be built with multiple missions (e.g., remote sensing with communications).

Along with these improvements in satellite capability, improved satellite propulsion will enable more flexible operations through easier repositioning. Major activities in a particular theater of operation that require dedicated communications or missile warning will be supported by geosynchronous assets moved into position for the duration of the campaign. Satellites that fail on-orbit will be replaced by on-orbit spares more quickly, since planners will not be constrained to selecting the lowest-consumption orbital maneuvers. The ability to move from one orbital track to another will also improve the chances of satellites’ survivability; e.g., if intelligence indicates an enemy is planning an anti-satellite attack the next time our satellite crosses over their territory, we will be able to shift that satellite into another orbit that crosses their territory at a different time. While the number of times we can make such shifts will be limited, even a few times may be enough.

These new satellites will not necessarily be cheaper than satellites being built today, since the research and development costs leading to these improvements must be recovered. Therefore, the numbers of satellites built and launched may not increase. Since in this scenario the cost of spacelift has not improved, the incentive will be to put the minimum of assets on orbit.

Will these more powerful, more agile satellites be any more useful to theater commanders? If they can be retasked to support contingencies, perhaps so. That ability will certainly make them more useful to the national decision makers, who will be able to count on them for the next contingency. Thus the perennial problem with moving expensive, limited-life spacecraft into other orbits, as with the communications satellite example above, will be solved—decision-makers need no longer weigh as heavily the immediate need against the loss of that asset to some other theater in the future.

Two: Off The Ground

This second scenario is a mirror image of the first, though less likely without a shift in research and development resources: We assume spacecraft propulsion may have improved a little but launch propulsion has achieved a significant improvement.

For almost everyone who ever watched a space launch—which in the US means practically everyone—propulsion means “rocket.” Whether you grew up watching Saturn-Vs lumber off the pad on their way to the moon or Shuttles leap off the pad on their way to low Earth orbit, the only way to get from here to there appears to be via smoke and fire. And because of the difficulty of the flight regime launch vehicles must traverse and the high development costs for new technologies, rockets will continue to carry us to orbit and propel us in orbit for quite awhile. But the mechanism for this assumed change in capability is less important than the result—a significant improvement in spacelift capability.

The most promising (in terms of payoff, not necessarily in terms of probability of success) approach to revolutionizing spacelift is the reusable launch vehicle (RLV), defined as “a completely reusable vehicle which is capable of achieving Earth orbit while carrying some useful payload and then returning.”[19] To achieve a truly reusable launch vehicle that can traverse the boundary from atmospheric flight to orbital maneuvering will require many technological advances—which, for example, the sub-orbital Ansari X-Prize winner did not have to achieve. While such a vehicle probably could not provide heavy lift capability, it should be sufficient to carry small payloads to orbit; in fact, its availability might lead to developing “less costly, and more capable, retrievable and reusable satellites that could be easily upgraded on the ground.”[20]

What would we expect such a vehicle to do? Several possible missions have been identified for a military-specific RLV, a few of which are: counterspace operations; protecting US and Allied space assets; intelligence, surveillance, and reconnaissance flights; satellite deployment, recovery, refueling and possibly repair; and “worldwide weapons delivery within minutes of launch.”[21] Some of these missions should be evaluated for the real payoff of conducting them from space, since “just because a…mission can be performed from space does not necessarily mean that it should be.”[22] Still, the benefits of a reusable vehicle for pure space applications are enormous. For example, “a rapid satellite deployment capability” would enable the US to “tailor the satellites, space forces, and other assets…to support warfighting…commanders in a timely and responsive manner”—the impetus for pursuing the Joint Warfighting Space and Operationally Responsive Space initiatives.[23]

Would improved spacelift capability drive any changes in the US approach to designing and producing satellites? Others have speculated a reusable launch vehicle would provide an incentive to produce smaller, modular satellites since it would be easier to bring them back to the surface for repair and upgrade. This leads us to consider whether, if launch cost goes down by more than an order of magnitude, we still need maximum reliability and maximum life in all of our satellites—especially if maximum reliability and life also lead to maximum cost. Is it possible satellites could go the way of computers: short lives, high turnover?

The military market for satellites is small enough that, because they are bought in small lots and their missions are unique, they will probably never become as disposable as most mass-produced items; therefore, the standard practice will continue to be to make military satellites as long-lived as possible. Still, having reliable and affordable access to space would allow for quick replacement of ailing or obsolete satellites. This idea of rapid, on demand space launch deserves further study.

The closest analogue to “on-alert” space launch is the fleet of intercontinental ballistic missiles (ICBMs) prepared to launch nuclear strikes. The advantage in this “alert” posture is that the payload does not change, but no one would recommend the US develop a fleet of rockets that sit ground alert with various types of satellites aboard. For one thing, satellites are not as robust as warheads; the cost of maintaining such delicate instruments, especially given the difficult problem of on-pad access, would be exorbitant.[24] For another thing, we do not have enough launch facilities to handle having so many vehicles "on the pad" at the same time; indeed we may not have enough for our current operational needs.[25] Thus satellite spares are either warehoused, powered-down and under tight environmental controls, or launched and kept as on-orbit backups.

An "on-alert" launch capability, then, would require a launch vehicle—reusable or not—that can be fitted with the appropriate payload and launched into the correct orbit. This will require a remarkable degree of commonality, since fitting a payload to a launch vehicle is not as simple as rolling a cargo pallet onto a C-17. And just as airlift uses different airframes to accomplish different types of missions, spacelift will continue to require different vehicle types to work with the range of payload masses (heavy lift, medium lift, etc.). Using a heavy lift booster to launch a light payload would be wasteful, and might not even work depending on the desired orbit—one difficulty of the previously mentioned Civil Reserve Launch Fleet concept. Within defined payload sizes, a "common" rocket type could be a good first step toward rapid launch capability, but having a common rocket does not solve all of the issues.

The common launch vehicle will require a common adapter that fits multiple payloads. "Fit," however, requires more than just mating the two mechanical surfaces together. If the aim is to speed the build-up and launch process, the common adapter must provide standardized power (voltage, amperage, DC or AC), cooling (available in a range, but not an infinite range), and communications signals (for telemetry and commands prior to launch and during flight)[26]—and all the satellites that would be fitted to the adapter must be built to similar power, telemetry, etc., standards. That is the rub: building different types of satellites that are all compatible with the common launch vehicle and adapter, and keeping both payloads and launch vehicles ready for call-up at a moment's notice.[27] And even if the satellite interfaces are identical, that does not mean the mission requirements for different types of satellites—their orbital parameters, attitude, etc.—will ever be the same.

One innovative idea for using a small launch vehicle to launch larger payloads is to design and build multi-part spacecraft that are assembled on orbit. "In the RLV world, as in the rest of the transportation world, if the cargo is too heavy to take in one trip, the solution is to put it in two boxes and make two trips."[28] This would work best for launching a moderate-sized satellite in one trip and launching an upper stage or orbital transfer vehicle in another, since the interfaces between them are limited. This idea might even work for a satellite bus and payload, if both were sufficiently modular and the interfaces and connections were simple enough.[29] Even for simple interfaces, however, such an assembly process is not trivial: the launch vehicle must have all the requisite tools to bring the pieces together, connect them, and check out the result. This would require some manner of mechanical arms to grasp both pieces, since the payload module probably would not carry its own propulsion system and firing the bus module's attitude control engines could damage payload components. This operation would probably require manned assistance, too, whether to tighten an electrical connection or improvise a solution to an unforeseen problem; for comparison, it is hard to imagine advancing the state of the art in the next 20 years to the point that Hubble Space Telescope repairs could be done remotely or robotically.

In addition to the nascent CONOPS already proposed or under development for such a system,[30] making these on-demand launch capabilities operational requires well-developed planning in advance of the systems' use. Decision trees that prioritize between types of launches for different contingencies must be built and exercised through as many scenarios as we can imagine. Instructions for how to deal with specific types of impediments (e.g., bad weather, enemy attack) must likewise be built and tested as realistically as possible. A robust system for quickly analyzing, planning, and re-planning trajectories for different types of launches in different situations must be developed. Doing all this for the launch and orbital operations is not enough, either; safe, reliable equipment and procedures for the ground operations (mating, fueling, etc.) must be in place, as well as procedures for their on-orbit counterparts.

With respect to on-orbit operations, one of the potential uses of a reusable launch vehicle is to replenish satellite propellants to increase the lifespan of the spacecraft. The prospect of fueling (or refueling) a space vehicle on-orbit points out the difference between operations in the flying and orbiting worlds. A pilot receives direct telemetry from his instruments of the amount of fuel left in his airplane, and knowing that can calculate how far he can fly. Satellite operators do not have the benefit of direct telemetry from electromechanical gauges. The fuel gauge in an airplane works because aviation fuel for the most part remains in a liquid state and its behavior in the tank is largely affected by gravity. Such an advantage is lost in free fall, where the liquid in a propellant tank may be affected more by surface tension and may fool attempts to gauge the remaining amount; as a result, a satellite operator is forced to calculate the remaining propellant by estimating how much was used in each thruster firing (x amount per pulse, y pulses per firing, etc.) and then she must compare those calculations with estimates from the material properties of the propellants (density, vapor pressure, etc., under conditions of tank pressure and temperature as read from telemetry). Truly operationalizing space travel will require making these mundane but important tasks more routine.

This is a daunting list of problems to be solved to make on-demand or on-alert space launch a reality. If, as speculated in this scenario, the propulsion engineers solve the technical problems of quick, reliable space launch, then the operators should be able to solve their portion of the problems. Doing so will enhance US space power by allowing the US to "seize"—figuratively at least—more of the "high ground" of space. Increased ability to operate at will in and through space will put us in charge of its "choke points."

> The view space provides and the capability to pass information through space at the speed of light from one point to another on the surface of the Earth makes certain satellite orbits more valuable, and hence busier than others. This leads to chokepoints in space. As in the case of the sea, the result is competition, and with competition will come conflict; from conflict, the necessity for space control.[31]

In addition to orbital choke points (which may not be "points" at all), a truly robust reusable space launch system that reduced the need for ground-based infrastructure would reduce the number of choke points on Earth.[32] For instance, the ability to operate from long runways with a small coterie of personnel and a small collection of ground equipment would reduce our dependence on our limited number of launch sites.[33] The system likely will not reach that level of maturity in the next 20 years, however, and budget constraints will limit the construction of any additional launch facilities, so those choke points will remain.

Problems To Overcome

The two scenarios above postulated incremental improvements, typical of slow, low cost, low technical risk development schemes. That approach presents increased risk that a would-be adversary may capitalize on technological advances before the US. What if a competitor jumps ahead in solar array and rocket propulsion technology?

From the two scenarios above, improved satellite propulsion and power would enable a potential enemy to build better satellites—communications, weather, reconnaissance—to support their own air, ground, and sea operations. Still not, perhaps, better than US satellites, but better than they would have been able to produce otherwise. More menacingly, these advances would also enable them to produce effective antisatellite vehicles (ASATs), whether designed to kill, disable, or interfere with our satellite systems. If, that is, we were even their primary target: they could just as well use their space systems against their less capable neighbors.

Improved launch propulsion would enable an adversary to loft their satellites into orbit more easily, thereby challenging us for control of the choke points in near-Earth space. They could also produce a direct-ascent ASAT vehicle, although many nations could do so today using existing technology. Furthermore, if we pull back from considering only space systems, improved propulsion could lead directly to improved ballistic missiles; thus the need, to prevent the proliferation of that technology, for strict enforcement of the Missile Technology Control Regime and vigilant oversight of cutting edge missile-related and dual-use technologies.[34]

Without a clear threat to US security and economic well-being, we are unlikely to mount a Manhattan Project for space power or propulsion. Space pursuits have become so commercial, even though space commerce has waned recently, that without government direction and funding companies will develop those technologies with perceived commercial payoffs first. Ideas with greater risk—or less assurance of payoff—will either languish or have to be pursued as small-scale efforts under the shadow of the main researches.

If the military is to capitalize on the technological advances needed to maintain US space superiority, we should have a stake in them from the beginning, which usually means investing in them. Given the difficulty meeting operational requirements on current budgets, and the reasonable expectation that neither the operational nor the budgetary pressure will abate soon, this will not be easy, especially since the defense appropriations system guarantees decisions on funding and research directions will not be made in a political vacuum. Some money will move based on political rather than purely technical payoff. Even within the political environment, however, public pressure for government accountability may help ensure taxpayer dollars are spent on needed research. In that light, acquirers must make every effort to ensure money is well spent, something that has not always been the case:

> Over emphasis on cost cutting measures was high on the list of recurring themes throughout the [launch failure investigation] reports. Criticism centered on pressure from the Air Force and NASA to reduce launch costs, combined with industry's desire to make a profit. The 'better, faster, cheaper' paradigm manifested itself in reduced staffing levels, diminished technical expertise (e.g., cheaper employees), and fewer procedural checks and balances.[35]

Despite the promise of "better, faster, cheaper," experience (and a little forethought) shows that usually we can have only two out of the three, not all three at once. Better and faster usually will be more expensive; faster and cheaper usually does not turn out to be better; and so forth.

* *

Currently, the US commands the military medium of space. Our use of space provides us with capabilities no other nation can match, but also presents us with limitations we must consider. We are electromagnetically connected to orbiting platforms just as surely as armies a century ago were connected to railroads, and at least from an orbital mechanics perspective we will not find it so easy to break free of those constraints. The space systems that enable us to strike "anytime, anywhere" are fragile, easily broken assets that require their own brand of logistical "tails" that are subject to enemy attack.

Projecting technological trends into the future, and noting that US research and development in salient fields is at least on par with the rest of the world,[36] we may conclude the US will maintain its lead in military-related space technologies for the next two or three decades. If our investments lag, however, we may expect our lead to decline. The remaining question is whether maintaining the lead is enough, or if we should focus our attention, effort, and treasure on extending it.

Notes

1. Manned flight does not fit this pattern; however, the lack of constant manned space activities did not materially reduce US military capabilities from space.

2. John M. Amrine, Lt Col, USAF, The Command of Space: A National Vision for American Prosperity and Security (Maxwell Air Force Base, AL: Air War College, March 2000), 111. Available on-line from https://research.au.af.mil; accessed 19 May 03.

3. Maj Lynn F. Connett, USAF, Is the US Launch Program Really Ready For the 21st Century? (Maxwell Air Force Base, AL: Air Command and Staff College, April 2000), 1. Available on-line from https://research.au.af.mil; accessed 19 May 03. Report number AU/ACSC/047/2000-04.

4. The Space Shuttle accounted for three to eight of the country's annual non-commercial launches from 1997-2002. Federal Aviation Administration,

Commercial Space Transportation: 2002 (etc.) Year In Review (Washington, DC: Associate Administrator for Commercial Space Transportation, January 2003 (etc.)). Available on-line from http://ast.faa.gov/rep_study/yir.htm; accessed 23 Apr 03.

5. See, e.g., Major Lina M. Cashin, USAF, Lessons From Sea Launch (Maxwell Air Force Base, AL: Air Command and Staff College, April 2001), 9. Available on-line from https://research.au.af.mil; accessed 19 May 03. Report number AU/ACSC/039/2001-04.

6. Analogous to the Civil Reserve Air Fleet.
See Michael A. Rampino, Concepts of Operations for a Reusable Launch Space Vehicle (Maxwell Air Force Base, AL: Air University School of Advanced Air Power Studies, June 1996), 37. Available on-line from https://research.au.af.mil; accessed 19 May 03.

7. Rather than one fleet, two separate fleets have been suggested: a communications satellite fleet and an imaging fleet. See Amrine, The Command of Space, 168-9.

8. See, inter alia, Lt Col Gregory M. Billman, USAF, The "Space" of Aerospace Power: Why And How (Pittsburgh, Pennsylvania: University of Pittsburgh General Ridgway Center for International Security Studies, May 2000), 22-3. Available from https://research.au.af.mil; accessed 19 May 03.

9. "Space superiority," as defined in Joint doctrine, would permit a force to operate space and "related land, sea, air and special operations forces…without prohibitive interference." Applying the definition of "air supremacy," "space supremacy" (undefined itself) would render "the opposing air force…incapable of effective interference." US Department of Defense, Joint Publication 1-02, Department of Defense Dictionary of Military and Associated Terms (Washington, DC: 12 April 2001 (as amended through 5 June 2003)), 29, 489.
Since no opposing force has yet interfered prohibitively with our use of space assets (the Iraqi attempt to jam GPS signals using "borrowed" Russian equipment cannot be called prohibitive), the US certainly has enjoyed space superiority to date.

10. MGen Franklin J. Blaisdell said, "We are so dominant in space that I pity a country that would come up against us." Quoted in Robert S. Dudney, "Space Power in the Gulf," Air Force Magazine, Volume 86, Number 6, June 2003, 2.

11. US Department of Defense, Militarily Critical Technologies List: Developing Critical Technologies, Section 19 (Dulles, Virginia: Defense Threat Reduction Agency, March 2001). This section pertains only to space systems.
The newest version of MCTL DCT Section 19 does not include the worldwide

technology assessments. US Department of Defense, Militarily Critical Technologies List: Developing Critical Technologies, Section 19 (Washington, DC: Defense Technical Information Center, October 2002). Available on-line from www.dtic.mil; accessed 14 May 03.

12. Preserving America's Strength in Satellite Technology, A Report of the CSIS Satellite Commission, Executive Summary (Washington, DC: Center for Strategic and International Studies, April 2002), viii. Available on-line at http://www.csis.org/tech/satellites/satellites/Satellitesexecsum.pdf; accessed 4 Jun 03.

13. Similar to the situation in which "Sputnik 1 may have led the Soviets to see space as a venue in which they could quickly and economically compensate for the advantages the United States enjoyed in other areas…." Sanford Lakoff and Herbert F. York, A Shield in Space? Technology, Politics, and the Strategic Defense Initiative: How the Reagan Administration Set Out to Make Nuclear Weapons "Impotent and Obsolete" and Succumbed to the Fallacy of the Last Move (Berkeley: University of California Press, 1989), 75.

Another example, more applicable to today, is kinetic weapons from space. See Bob Preston et al., Space Weapons, Earth Wars (Santa Monica, California: RAND, 2002), 40. Available on-line from http://www.rand.org/publications/MR/MR1209/; accessed 27 Mar 03. RAND Report MR-1209-AF.

14. US Department of Defense, Militarily Critical Technologies List: Appendix A, Glossary (Washington, DC: Defense Technical Information Center, February 2002), A-32 and A-9. Available on-line from www.dtic.mil; accessed 14 May 03.

15. US Department of Defense, Militarily Critical Technologies List: Weapon System Technologies, Section 17 (Washington, DC: Defense Technical Information Center, March 1999), 17-1. Available on-line from www.dtic.mil; accessed 14 May 03.

16. MCTL Developing Critical Technologies, Section 19 (2002 version), 19-1.

17. The comment about electronics is paraphrased from a toast made by a Russian engineer during a banquet. The banquet celebrated the successful fit check and separation test between a US-made commercial communications satellite and its Swedish-made launch vehicle adapter. The fit check was in preparation for the satellite's launch from Kazakhstan on a Russian booster, after which the satellite would be turned over to its Canadian owner.

18. Benjamin S. Lambeth, Mastering the Ultimate High Ground: Next Steps in the Military Uses of Space (Santa Monica, California: RAND, 2003), 145. Available on-line from http://www.rand.org/publications/MR/MR1649/; accessed 2 Jul 03. Report number MR-1649-AF.

19. Rampino, Concepts of Operations for a Reusable Launch Space Vehicle, 11.

20. Daniel R. Gonzales et al., Proceedings of the RAND Project AIR FORCE Workshop on Transatmospheric Vehicles (Santa Monica, California: RAND, 1997), 11. Available on-line from http://www.rand.org/publications/MR/MR890/#contents; accessed 27 Mar 03. Report number MR-890-AF.

21. Billman, The "Space" of Aerospace Power, 190.

22. Lambeth, Mastering the Ultimate High Ground, 156 (emphasis in original).

23. Gonzales et al., Proceedings…Transatmospheric Vehicles, 11.

See also, inter alia, Henry S. Kenyon, "Express Launch to Space," Signal, Volume 157, Number 11, Jul 03, 27.

Joint Warfighting Space and Operationally Responsive Space may turn out to be good first steps toward a useful RLV.

24. The delicate nature of spacecraft is itself another factor making routine spaceflight difficult. In addition, rockets themselves—and especially US rockets—are often built to the edge of their design capabilities. See Gray Rinehart, "Remember the Orion!," Space Energy and Transportation, Volume 2, Number 1, 1997, 46-7.

25. "[More] launch pads will allow a margin to handle launch 'surges,' accommodate launch slips, support anomaly resolution, and accept pad downtime for modernization." Cashin, Lessons From Sea Launch, 23.

26. See, e.g., Major Austin D. Jameson, USAF, X-37 Space Vehicle: Starting a New Age In Space Control? (Maxwell Air Force Base, AL: Air Command and Staff College, April 2001), especially 13. Available on-line from https://research.au.af.mil; accessed 19 May 03. Report number AU/ACSC/063/2001-04.

27. See Lt Col Henry D. Baird et al., "Spacelift 2025: The Supporting Pillar for Space Superiority," A Research Paper Presented To Air Force 2025 (August 1996, Maxwell Air Force Base, AL: Air War College, August 1996), 11. Available on-line from http://www.au.af.mil/au/2025/; accessed 17 Jun 03.

See also Rampino, Concepts of Operations for a Reusable Launch Space Vehicle, 17-20.

28. William W. Bruner III, National Security Implications of Inexpensive Space Access (Maxwell Air Force Base, AL: School of Advanced Airpower Studies, 1996), 25. Available on-line from https://research.au.af.mil; accessed 19 May 03.

29. See “Space Modular Systems,” Spacecast 2020 Appendix K (Maxwell Air Force Base, AL: Air University, Jun 92). Available on-line from http://www.au.af.mil/Spacecast/; accessed 17 Jun 03.

30. See, e.g., Rampino, Concepts of Operations for a Reusable Launch Space Vehicle.

31. Thomas D. Bell, Lt Col, USAF, Command and Employment of Space Power: Doctrine for the Asymmetric Technology of the 21st Century (Maxwell Air Force Base, AL: Air War College, April 1997), 9. Available on-line from https://research.au.af.mil; accessed 19 May 03. Air University Report AU/AWC/RWP011/97-04.

32. See Bruner, National Security Implications of Inexpensive Space Access, 36, and James E. Oberg, Space Power Theory (Colorado Springs, CO: US Space Command, Mar 99), 6.

33. See Cashin, Lessons From Sea Launch, 23.

34. The Missile Technology Control Regime (MTCR) was created in 1987 to “restrict the proliferation of nuclear-capable missiles and related technology.” US Department of State, “Missile Technology Control Regime (MTCR)” (Washington, DC: Bureau of Nonproliferation, October 9, 2001). Available on-line from http://www.state.gov/t/np/rls/fs/2001/5340.htm; accessed 19 Jul 03.

35. Connett, Is the US Launch Program Really Ready For the 21st Century?, 6.

36. See, e.g., MCTL Developing Critical Technologies, Section 19 (2001 version).

Contributor

Lt Col Graham W. "Gray" Rinehart (BS, Clemson University; MS, Golden Gate University) is a member of the Secretary and Chief of Staff of the Air Force's Executive Action Group. He was previously Program Manager for Space Technology Policy in the Defense Technology Security Administration. He has also commanded the USAF's largest satellite tracking station at Thule AB, Greenland; served as operations officer of a mobile command and control squadron; and held a variety of operations and engineering positions. He is the author of one book and over a dozen articles, essays, and technical papers.